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Virtual Reality: Immersed in the Structural World

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Synopsis

Virtual Reality is a rapidly emergent technology, driven by the computer gaming industry. The maturity of the concept, combined with modern hardware is delivering an experience which offers a useful commercial tool for industry and educators. This article presents the uses of virtual reality within structural engineering and provides an understanding of how it can be incorporated easily and efficiently, for design purposes and beyond.

Introduction

Oculus VR was founded in 2012 with the aim of developing a virtual reality headset for computer gaming and was crowd funded to a value of \$2.4million¹. In March 2013 Facebook acquired Oculus VR for \$2.1billion². What has virtual reality and computer gaming got to do with Structural Engineering?

Virtual reality technology is strikingly relevant to both engineers and architects for both educational purposes and as a design aid. Virtual reality is a concept in which a headset is placed over the user's head that contains two lenses which provide a stereoscopic view of a computer generated world. The images on the screens update in real time to mirror the orientation and position of the user's head. The technology has been used in the manufacturing sectors such as naval, automobile and aerospace and also product design. In November 2014 BAE Systems announced that they were introducing virtual reality to help design and build new ships for the Royal Navy³. They claim that the technology helps engineers to spot design flaws and safety issues before the steel is cut preventing costly design changes later on. Company size in these sectors tends to be large and thus investment is more easily justifiable than for most SMEs.

However, recent developments in low cost virtual reality technology has created an opportunity for low cost hardware, namely Oculus Rift, to be utilised in the conceptual design process for Civil and Structural engineers. The authors have used Oculus VR's Development Kit 2, priced at approximately £300, to allow designers to *enter* their creations and thus provide a completely immersive experience.

The initial rationale for utilising virtual reality at Queen's University Belfast was to enable undergraduate students to be able to develop a sense of scale and three dimensional spatial awareness. Typically, students at an early stage of their careers are comfortable working in a two dimensional manner; in plan, section and elevation. Problems can arise as they attempt to differentiate structural supports and load paths through floors, from non load bearing spatial dividers. Physical models are of benefit but can be time consuming to construct and difficult to alter should they illustrate flaws in the design. Virtual reality can offer an alternative method of developing these skills. Furthermore, interoperability with common structural and architectural design software, such as AutoCAD and Revit has opened the potential deployment to industry. It

offers much more than a flythrough experience; it puts the viewer *into* the building and creates a sense of *presence*.



Figure 1 Model of Rudin House created by second year Structural Engineering students

Virtual Reality

Virtual reality as a concept has been around since the 1930's, first proposed by French playwright Antonin Artaud in his collection of essays, *The Theatre and Its Double*⁴. However, it was 1968 by the time that the first virtual reality headset was created. Ivan Sutherland and Bob Sproull created the first virtual reality head mounted display, called the *Sword of Damocles*, at Harvard University⁵. The headset itself was so heavy it had to be hung from the ceiling while being used. This paved the way for future developers and since then virtual reality has grown in popularity.



Figure 2 First head mounted display, Sword of Damocles (1968)



Figure 3 Oculus Rift DK2 and IR camera

Virtual reality appeared to be moving to commercial uptake in the 1990's, with the release of hardware, such as the Virtual Boy⁶ by Nintendo along with numerous others. However rudimentary computing power, limited graphics ability and relatively high cost for non colour display were factors attributed to its limited success. Twenty year later technological advancement, namely in mobile phone hardware as well as computing graphics ability, has resulted in the creation of a much more convincing experience. Display screens used in mobile phones are reaching sufficient resolution that individual pixels can not be distinguished, even at the extremely close viewing distance used in virtual reality headsets. Positional tracking and refresh rate on the screens are sufficiently short that the latency associated with motion sickness has been eliminated.

Health warnings come with using the Oculus Rift, which are projected onto the screen at the start of projects. The most common side effect is motion sickness, although this can be reduced with higher resolution models and textures. Such negative effects have also been lessened with each new development kit, a trend which appears set to continue, as reported by the few people who have experienced the unreleased third iteration of the Oculus Rift (Crescent Bay).

Side effects can also be lessened by ensuring that the user stays seated during use and by not using the Rift too often for long periods of time. Indeed, the Oculus Rift Health and Safety Manual states that *“The headset produces an immersive virtual reality experience that distracts you from and completely blocks your view of your actual surroundings. Always be aware of your surroundings when using the headset and remain seated at all times”*

The long term effects of contemporary VR technology are not yet known, however studies from the 1990's suggest that prolonged use can result in disassociation with reality. Discussion of the effects of the technology are generally relating to prolonged exposure⁷. The applications suggested within this article are focused on short term exposure.

Timeliness of hardware and software integration

Simulation of 3D environments exists at various levels, ranging from non immersive right through to fully immersive virtual reality. Non immersive 3rd person perspective and non immersive 1st person perspective (Revit walkthrough) can be offered using conventional computer screens and hardware. A 3D theatre with multiple screens surround the user offers a semi immersive experience but requires large space, multiple projectors and specialised software to generate the required images to be displayed. Fully immersive virtual reality generates stereoscopic images of the 3D environment, completely filling the field of view, and updates in real time to display what the user believes they are looking at.

The initial aim of this study was to enable Structural Engineering students to view SketchUp models they had created, both Architectural and Structural, in virtual reality. As a learning experience they would gain an appreciation of overall building heights, floor to ceiling heights, span of beams, vertical continuity of load paths all at an effective scale of 1:1 and essentially see their designs as *constructed*. However, would virtual reality be useful in structural engineering? Would it reduce the cost of new builds? Extensive use of Revit and other 3D modelling programs in today's engineering industry would lead many people to answer no. Given that tightening BIM legislation is bringing more small scale projects to a point where 3D models are generated, the resource commitment to convert those models to a virtual world is extremely modest. In fact it is little more than the cost of the initial hardware outlay.

There are a number of programs which facilitate walk through or fly through in building without the need for a virtual reality headset. However, actually placing yourself into a structure and being able to look around 360°; being able to move freely around the building and view how it will look during and after construction is a vastly different scenario. The client can enter their structure before it is built and *experience* the creation. This sense of presence is the current goal of modern virtual reality and for all intentional purposes it has been achieved, and achieved at a very low budget.

Process of conversion from 3D model to VR experience

Whilst there are other suppliers of virtual reality headsets, this research was focused on using the Oculus Rift DK2 and the process described hereafter are for that particular equipment and associated software.

Initially a 3D model is created in either SketchUp, Revit or AutoCAD 3D, AutoDesk Maya 3D. These models are then converted to run in a games engine, in this case Unity 4. Viewpoints are established within Unity along with physical constraints of the model. The resultant model can be saved as an executable file to run any computer and viewed with the Oculus Rift. The precise process varies depending on the precursor software and is described below for SketchUp and Revit.

Sketch Up

Create the SketchUp model and render using the textures available within SketchUp ensuring all faces are orientated the same direction (any faces that are not on the same plane will be grey in colour when switched to monochrome view). To be able to open the model in Unity it must first be exported at an acceptable file format, the most common being '.FBX'. This file can then be viewed as a 3D model in the 'Scene' tab within Unity. Textures, Light Paths, Terrains etc can then be identified if necessary. By importing the "Oculus Rift Integration" file, a *player control object* can be assigned to the model. This is the object that allows the model to be seen through the stereoscopic view – as it would be within the headset. Once the player control location is set and the model has been tested within the Unity "game" tab it can then be saved and exported as an executable application (.exe) file. This executable file can be opened without Unity and will be displayed directly on the headset. This means that the file can be easily transferred between different people and can be viewed on any computer (providing it has been set up with the headset).

Revit

Once a Revit model has been created it also must be exported as an '.FBX' file. However the resultant '.FBX' file must be opened with a program called 3DS Max. The reason this is done is because Unity does not support the Autodesk Materials Library, so any textures or renders given to the model within Revit will not transfer into Unity. Within 3DS Max it is possible to convert any Autodesk materials into standard materials. Once the materials have been converted to the standard materials the model can then be saved as a .FBX again and imported into Unity. Once the model is complete with the player controller location it can then be exported and run as a separate application, as with a SketchUp process.

Other Programs

The process for bringing a Revit file into Unity is the exact same as the process for bringing any 3D Model from any of the Autodesk programs. i.e. AutoCAD 3D, Autodesk Maya 3D etc. All Autodesk programs have the option to export the model as .FBX files and as long as the materials are converted to standard within 3DS Max, the model can be integrated with Unity to create a VR application.

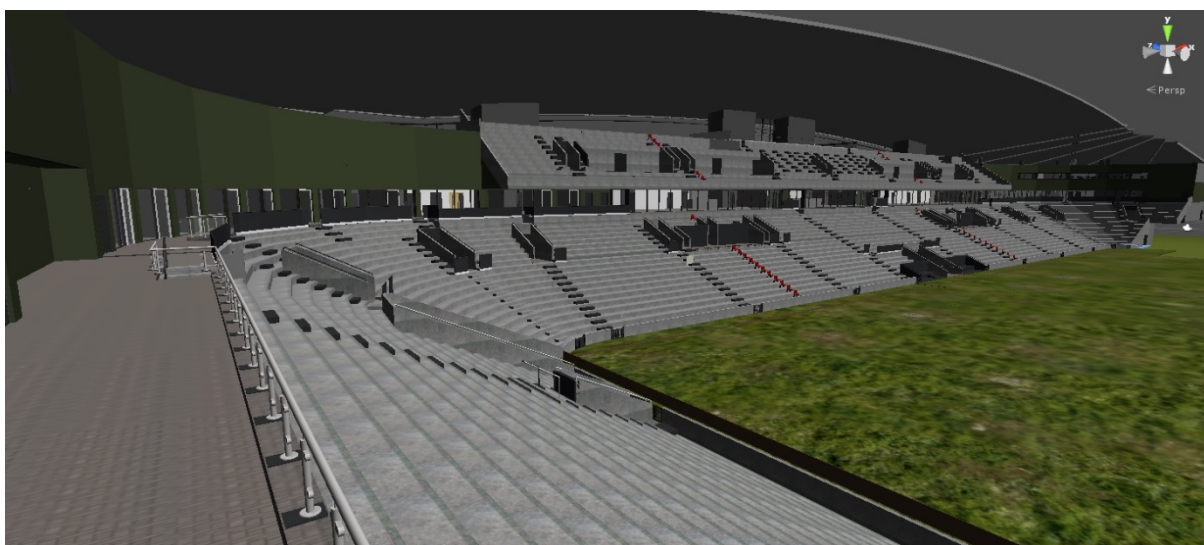
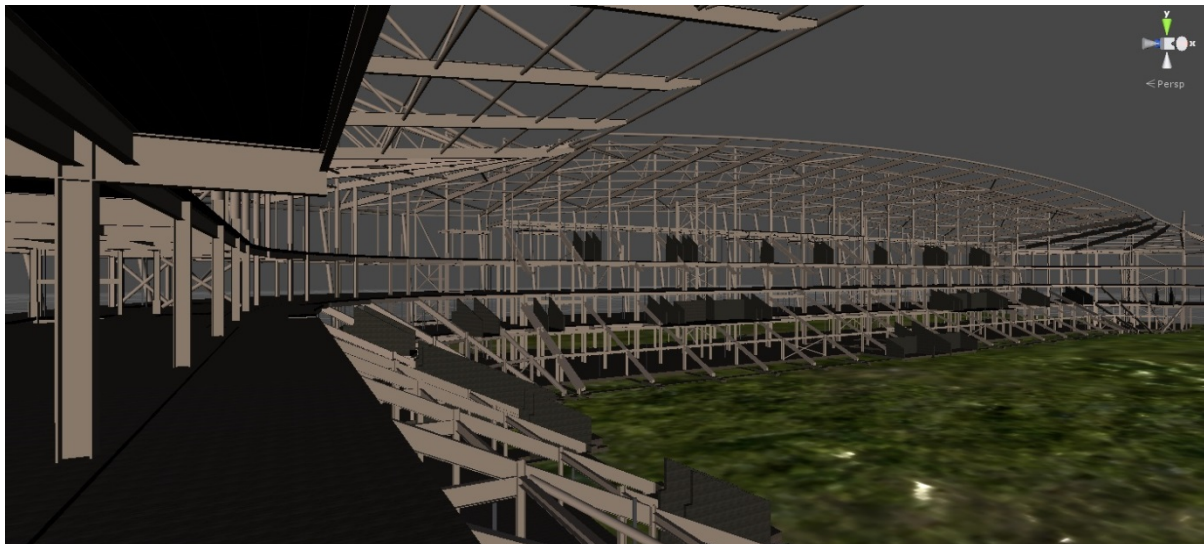
Unity

Unity is a game development program where users can model and create their own games for multiple platforms including websites, mobile devices and consoles. The easy to use export feature allows you to choose which platform you wish to play the game on and creates a playable file for that platform. With the large interest in virtual reality recently, Unity have updated their software to enable users to create games for virtual reality platforms. Now that Oculus Rift and Unity have joined together in a partnership it has become even easier to create content for visualisation within

the Rift headset and it is the only program that will allow an application to be developed and played on any computer without the need for the gaming software to be installed on the computer.

Windsor Park Case Study

Windsor Park in Belfast is the main soccer facility in Northern Ireland and is currently under redevelopment to provide new spectator grandstanding on the South and East sides. The conceptual design was by Hamilton Architects. Revit models were created by the Design and Build Architect, Holmes Millar and the Structural Engineer, AECOM. O'Hare and McGovern commenced construction in May 2014 and the stadium is expected to be completed in October 2015. The models were not created with virtual reality compatibility in mind however, the conversion process described above was applied and the virtual reality world was enterable within half a day. Both the steel frame structural model and the finished design and build models integrated seamlessly with the virtual reality hardware and software. For larger models such as Windsor Park will demand more computing power. This is to enable textures to be updated at sufficient speed to avoid the viewer noticing *pop-in*, were by the image on the display shows surfaces with no textures initially until the computer can generate them at which point they appear.



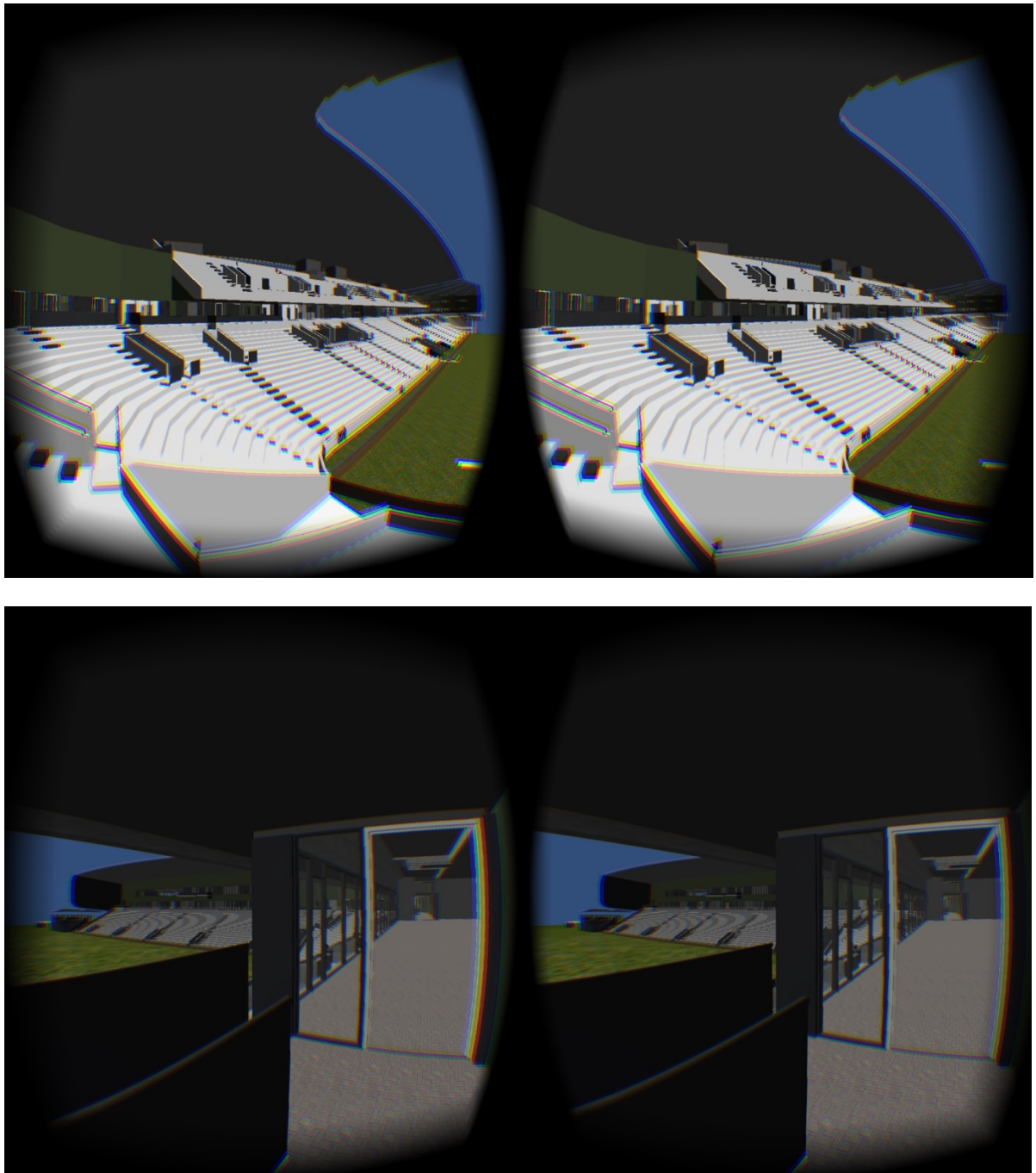


Figure 4 Windsor Park Revit and Unity VR models

At this stage it is difficult to discuss quantitatively changes in productivity as the technology is not commercially available and in widespread use. The authors have focused on the process of implementation as the initial stage of deployment. However, anecdotally, errors within models have been observed by multiple users, such as over projection of barriers and screens. Such errors are likely noticed due to the 1:1 scale when the user is within the virtual environment.

Virtual Presence

The design application described previously allows the user to experience virtual a building or structure before it is realised physically. A key aspect of virtual reality that should be considered is

the potential of virtual presence. In essence this encompasses any application of the technology that allows human presence in an environment, be it virtual or physical. By deployment of suitable remote sensing equipment, such as robotic mounted cameras, a user may be placed within a real environment that may be hazardous to humans. This could be of use to emergencies services, security services and technical assessment teams. Structural assessment of fire, earthquake or toxic environments could be conducted remotely and safely. Whilst remote access assessment currently exists, it has the drawback of leaving the user clearly detached from the situation. Existing, expensive equipment could potentially be upgraded to offer an immersive environment at limited cost and no change to the hardware. Furthermore, the technology could be utilised for training of personnel to respond to such scenarios in a safe manner.

Conclusions

The low cost of the hardware, easy of adopting commonly used existing software hint of a future where virtual reality will be a common place in design. The illusion of the virtual world is convincing enough to encourage users to attempt to reach out and touch objects which their brain suggests is present. At that point the illusion is broken, thus the next challenge for this technology is developing a natural way to interact with such virtual worlds.

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